Update to Hazard Assessment of Selenium Contamination at Benton Lake National Wildlife Refuge

Service Unit: Benton Lake NWR
Species or group: Wetland contamination
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Summary

The levels of selenium in all trophic levels in Unit 1 on the refuge continue to be a concern. The mean concentration of selenium in water, sediment, macroinvertebrates and aquatic bird eggs were all above the "minimal" hazard level identified as the desired objective for the refuge. The overall hazard ranking for the unit is "high", which denotes a toxic threat sufficient to cause complete reproductive failure in sensitive species of aquatic birds (e.g. waterfowl). The selenium data from 2011 indicate that selenium hazard is at least similar to 2008, and is likely increasing. There is no evidence that selenium levels are on a downward trend. This is consistent with what would be expected based on the recent increases in natural run-off, which increase selenium inputs, and modeling of selenium cycling on the refuge (Zhang and Moore 1997).

Introduction

The potential for a selenium contamination problem at Benton Lake National Wildlife Refuge (NWR) was first identified in 1985. Subsequently, numerous studies have been conducted to understand selenium dynamics on the refuge as well as document and track the selenium contamination levels and model future scenarios (Knapton et al. 1988, Lambing et al. 1994, Nimick et al. 1996, Zhang and Moore 1997, Henny et al 2000, refuge studies 2006, 2008). Through these studies, selenium has been sampled in refuge water, sediment, macroinvertebrates and birds (livers, eggs). The results have been variable, but all of these studies have found selenium concentrations moderately to considerably higher than established standards and sufficient to impair reproduction in sensitive species, such as waterfowl, in some portion of the samples collected (Figure 1).

Selenium enters the refuge via natural run-off from the surrounding Lake Creek watershed and from water pumped annually from the neighboring Muddy Creek watershed. From 1970-2010, the total selenium load into the refuge is estimated to be 6,202 lbs. Of this, 61% (3,785lbs) came from natural run-off and 39% (2,417lbs) came from water pumped from from Muddy Creek. Selenium is removed from the refuge primarily by transferring directly to the air from water or sediment (volatilization). The rate of selenium volatilization depends on several factors, but is much higher from exposed sediment than open water (Zhang and Moore 1997).

Although selenium is transported to the refuge in the surface and ground water that flows to the refuge, almost all of the selenium entering the refuge accumulates in wetland sediment. Selenium is not evenly distributed among or within the wetland units but rather accumulates more rapidly near the locations of the primary selenium inputs (Zhang and Moore 1997). In general, selenium concentrations in sediment are highest where Lake Creek enters Unit I and in Unit IVc near a large seep on the refuge (Knapton et al. 1988, Nimick et al. 1996, Zhang and Moore 1997, refuge studies 2006, 2008).

A comprehensive conservation plan (CCP) that will guide the management of the refuge for the next 15 years is currently in the draft stage. All of the alternatives for future management attempt to reduce or reverse selenium accumulation to levels where it is no longer a hazard for wildlife ("minimal" hazard). In anticipation of implementing one of these alternatives when the CCP is completed, a sampling effort was begun in 2011 to develop an updated baseline for selenium contamination on the refuge. Regardless of the alternative that is selected, reducing selenium levels in Unit 1 is a high priority. This report summarizes selenium sampling conducted in 2011 for Unit 1 on the refuge.

Methods

Sampling in 2011 focused exclusively on Unit 1. We measured selenium levels at 4 trophic levels (water, sediment, macroinvertebrates and waterfowl eggs) according to the Lemly protocol (Lemly 2002). This protocol assigns a level of contamination hazard to each trophic level individually and provides a method for combining these elements to make an overall contamination hazard assessment for a specific location. This method accounts for the bioaccumulation, and increasing hazard, as selenium is passed up the food chain.

Hazard Level	Definition	Water (µg/L)	Sediment (µg/g)	Inverts (µg/g)	Eggs (µg/g)
None	No toxic threat	<1	<1	<2	<3
Minimal	Selenium elevated, but no toxic threat	1-2	1-2	2-3	3-5
Low	May marginally affect sensitive species	2-3	2-3	3-4	5-12
Moderate	May substantially impair reproduction	3-5	3-4	4-5	12-20
High	May cause complete reproductive failure	>5	>4	>5	>20

In order to collect all trophic levels in the same time frame, sampling took place during June when waterfowl eggs were available. Waterfowl are known to be sensitive to selenium contamination. Samples were collected using techniques described elsewhere (Nimick et al 1996, Zhang and Moore 1997, Refuge files 2006, 2008).

The Lemly protocol only requires one sample from each trophic level, however, we collected additional samples to better characterize and understand the range of selenium contamination levels in Unit 1. Of the four trophic levels, sediment is the major reservoir of selenium within refuge wetlands. It is also highly variable across the wetland. With the help of USGS, we conducted a power analysis to determine how many samples we should collect to maximize our ability to detect changes in selenium levels in the sediment, while balancing cost and collection effort. This analysis indicated that 54 samples would allow us to be 95% sure of accurately detecting a change in selenium levels of at least 0.5 µg/g. We created a systematic grid across the open water area of the wetland (sampling within cattails was considered logistically prohibitive), and collected 63 samples from the upper 2cm of sediment. Five evenly spaced locations within this grid were chosen for water and macroinvertebrate samples as well. Eggs were collected by systematically searching the perimeter of the wetland up to 200m. Twenty-one waterfowl nests were found and one egg was collected from each.

Results

A complete listing of the raw data, and associated hazard score, for all of the samples can be found in the spreadsheet *BNL_Seleniumdata_2011_prelim.xls*. For all trophic levels, the refuge has set an objective of "minimal" hazard as the highest acceptable. Minimal hazard is where selenium levels may be elevated relative to uncontaminated reference sites, but no imminent toxic threat exists (Lemly 2002). While "minimal" may be considered relatively conservative, all hazard levels above this would indicate there is at least some potential for impairment to trust resources.

The "minimal" threshold for concentrations of selenium in water is 2µg/L. Three of the five water samples were above this threshold (Figure 2). The highest value was 5.46µg/L, which is "high" (toxic threat sufficient to cause reproductive failure). This sample was collected near the middle of the open water in Unit 1. The mean of the five samples was 2.92 µg/L (95%CI = 1.57–4.27µg/L)

The "minimal" threshold for concentrations of selenium in sediment is 2µg/g. Fifty of the sixty-three sediment samples were above this threshold. Thirteen of the samples were above 4µg/g, or "high". Some of these highly toxic samples were near the inlet of Lake Creek, but several were at the other end of the unit nearer to the dike (Figure 2). The mean of the 63 samples was 3.04µg/g (95%CI = 2.74–3.34µg/g)

Selenium was sampled in the sediment in Unit 1 previously in 1994 and 2008 at a consistent set of 12 locations. Sediment sampled in 2011 at sites very near to these previous sample locations is summarized in Table 1.

Table1. Selenium concentrations in sediment from similar locations in Unit 1 in 1994, 2008 and 2011.

	Unit I		
Year	1994	2008	2011
	Se (ug/g)	Se (ug/g)	Se (ug/g)
	2.62	4	2.63
	1.78	4.3	3.51
	1.39	3.1	3.51
	1.29	2.6	4.51
	2.23	1.9	2.12
	2.28	1.7	2.44
	1.51	1.8	1.81
	1.48	2.5	3.56
	1.13	2.9	3.19
	2.33	2.1	1.72
	1.83	2.5	1.98
	1.06	3.1	2.17
Mean	1.74	2.71	2.76
95%CI	+/-0.29	+/-0.47	+/-0.49

The “minimal” threshold for concentrations of selenium in macroinvertebrates is 3µg/g. All but one of the five samples were above this threshold. The highest value was 4.77µg/g, which is “moderate” (sufficient to substantially impair, but not eliminate reproductive success). The mean of the five samples was 3.89µg/g (95%CI = 3.17-4.61µg/g)

The “minimal” threshold for concentrations of selenium in aquatic bird eggs is 5µg/g. We collected one egg each from nests of 7 blue-winged teal, 4 northern shovelers, 3 gadwall, 6 mallards and one northern pintail. There was no apparent relationship between selenium concentration and species. Half of the eggs were above the minimal threshold. The highest value was 11.60 µg/g found in a mallard egg, which is “low” (marginally affect reproduction in sensitive species). The mean of the 21 samples was 5.67µg/g (95%CI = 4.48-6.86µg/g).

Selenium concentrations measured at multiple trophic levels can be combined to create an overall hazard level (Lemly 2002). The sample with the highest concentration at each trophic level was used in the overall assessment in order to be the most conservative in estimating hazard. The overall hazard assessment is “high” (Table 2). An overall assessment of high indicates that reproduction failure may be currently occurring in aquatic waterbirds on the refuge. This is similar to an assessment in 2006 for Unit 1, but the “score” for the unit has increased from 16 to 17 based on the individual components (Table 2).

Table 2. Overall hazard assessment for Unit 1 (2006 and 2011).

	2006		2011	
	Se	Rank	Se	Rank
Water (µg/L)	2.2	Low	5.46	High
Sediment (µg/g)	4	High	7.58	High
Invertebrates (µg/g)	7.65	High	4.77	Moderate
Eggs (µg/g)	8.71	Low	11.6	Low
Overall Hazard		High (16)		High (17)

Discussion

The levels of selenium in all trophic levels in Unit 1 on the refuge continue to be a concern. The mean concentration of selenium in water, sediment, macroinvertebrates and aquatic bird eggs were all above the "minimal" hazard level identified as the desired objective for the refuge. The overall hazard ranking for the unit is "high", which denotes a toxic threat sufficient to cause complete reproductive failure in sensitive species of aquatic birds (e.g. waterfowl).

Compared to sampling conducted in 2006, the overall hazard ranking is the same, but the "score" used to derive that ranking has increased from 16 to 17 out of 20 (Lemly 2002). The mean concentration in the sediment in Unit 1 is 3.04µg/g. Previous research and modeling on the refuge has identified 4.0 µg/g as the toxic threshold beyond which severe consequences are expected, such as those that occurred at Kesterson NWR prior to capping of refuge wetlands (Nimick et al 1996, Zhang and Moore 1997).

Sediment samples in 2011 located near locations previously sampled in 1994 and 2008 suggest an increase in selenium in the sediment, but it may not be statistically significant, especially between 2008 and 2011. Selenium in sediment is highly variable, and unfortunately, the number of samples from the historical datasets (1994, 2008), are not adequate to detect smaller (<0.5µg/g) increases in selenium. The 2011 estimate of the mean selenium concentration is based on 63 samples which will provide a better baseline for monitoring going forward.

The selenium data from 2011 indicate that selenium hazard is at least similar to 2008, and is likely increasing. There is no evidence that selenium levels are on a downward trend. This is consistent with what would be expected based on the recent increases in natural run-off, which increase selenium inputs, and modeling of selenium cycling on the refuge (Zhang and Moore 1997).

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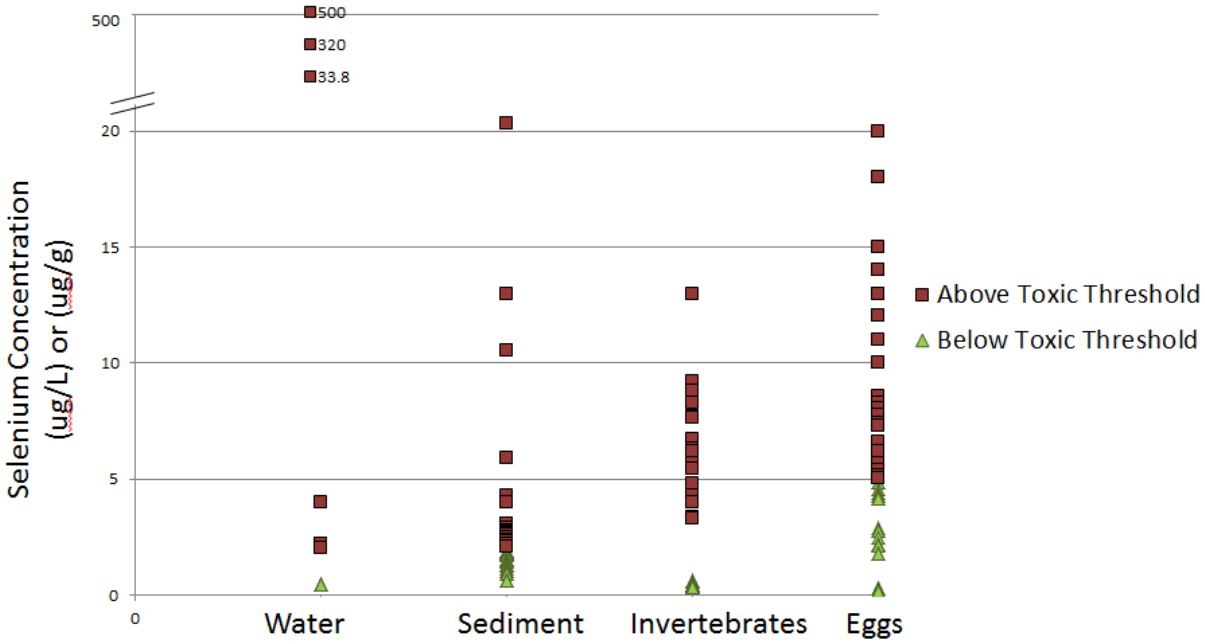

Figure 1. Range of selenium concentrations from water, sediment, invertebrate and egg samples across Benton Lake refuge from 1986-2008 (n=183 samples total). (Knapton et al 1988, Nimick et al 1996, Zhang and Moore 1997, Refuge Files 2006-2008).

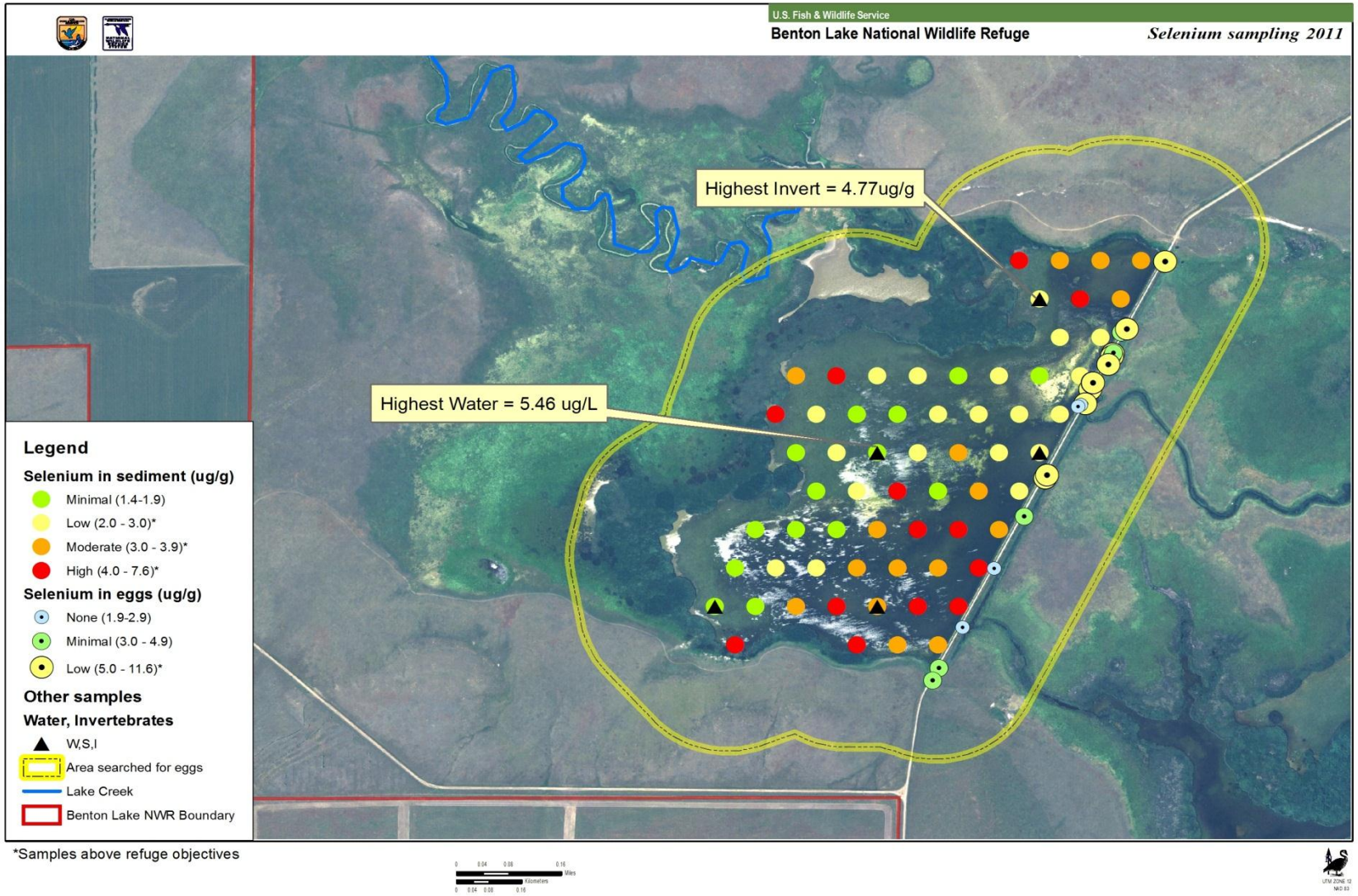

Figure2. Selenium sampling in Unit 1 during June of 2011.